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(54) Semiconductor Integrated Circuit Structure

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SPECIFICATION

1. Title of the Invention:
   Semiconductor Integrated Circuit Structure

2. Claims:

(1) A semiconductor integrated circuit structure comprising a plurality of unit circuits each including a semiconductor electronic element formed on the same and one substrate, and a transmission path for transmitting signal information from a transmission section in one unit circuit to a reception section in another unit circuit,

wherein the transmission section is composed of an electro-photo-converting light-emitting element, and the reception section is composed of a photo-electro-converting light-receiving element, and the transmission path is composed of an optional waveguide.

(2) The structure according to claim (1), wherein the optical waveguide is used for only a pair of the transmission section and the reception section.

(3) The structure according to claim (1), wherein the optical waveguide is commonly used for a plurality of pairs of the transmission section and the reception section.

(4) The structure according to claim (3), wherein the light-emitting element of the transmission section has non-directivity.

3. DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to the improvement of a semiconductor integrated circuit structure having some unit circuits, which is constituted to require the transfer and reception of information signals between the unit circuits, and particularly to a semiconductor integrated circuit structure for achieving high-speed transmission of information signals.

There are frequently used semiconductor integrated circuits formed by integrating a plurality of unit circuits each having component(s) such as bipolar or MOS transistors on the same and one substrate, in which the transfer of information signals is performed between the unit circuits. By the way, the transmission of information signals in any conventional ones is performed by carrier's flow or electric current.

Namely, both reception section and transmission section are composed of transistor or the like as a semiconductor electronic device, and between them there is naturally provided with transmission paths which are conductive wiring paths composed of a metal or the like.

However experiences up to the present indicate that an improvement of integration density will make a progress much more in the future, and it is therefore expected that as unit circuits themselves or elements of each unit circuit become

minute, unit circuits disposed on one substrate are greatly increased in number and become complicated, while it is also expected that the length of the wiring connected among the unit circuits is increased.

Then, if miniaturization makes shorter the time required for unit circuit itself to process electric signals, it is a sufficient fear that time delay of passing electric signals through signal transmission paths among the unit circuits becomes unchanged or longer, thereby deteriorating improvement of overall performance of integrated circuit which has been expected owing to miniaturization in dimension.

In view of the above-described situations, it is an object of the present invention to provide a semiconductor integrated circuit structure having a plurality of unit circuits mounted on the same and one substrate in which the time required for propagating information signals among the unit circuits can be shortened, thereby suppressing the time delay.

In short, the feature of the present invention resides in that instead of transmitting electric signals as they are in the prior art, electric signals are converted once into optical signals to transmit them, and in other words, there is provided with a semiconductor integrated circuit as a whole wherein information signal transmission paths among the unit circuits are composed of an optical waveguide path. A high-speed signal transmission is thereby achieved as a desired object, which will be verified by the following knowledge or principle.

The following equation almost shows the delay time T_{DE} of signal transmission in the semiconductor integrated circuits of the conventional system in which the transfer and reception of signals among unit circuits or unit systems are performed with electric signals by connecting their input and

output elements with a wiring made of a conductive material such as a metal.

$$T_{DE}=C_W L(\Delta V)/I_0 \qquad \dots (1)$$

Here, C_W denotes a capacitance per unit length of the wiring, L denotes a length of the wiring, ΔV denotes voltage variation required for detecting signals, and I_0 denotes an output current which can be supplied for driving an output device. On the other hand, in mode of using optical signals, time delay in an optical waveguide path becomes lower to the extent of being negligible, and then delay time T_{DO} of signal transmission is approximately expressed as the sum of delay time T_{DOE} from starting of driving of a light emitting element to light emission of the light emitting element and delay time T_{DOD} from light receiving of a light receiving element to outputting of voltage variation required for detecting signals. That is,

$$T_{DO}=T_{DOE}+T_{DOD} \qquad \dots (2)$$

When the driving current of the light emitting element is assumed to be the same as outputting current I_0 in the conventional system for comparison, T_{DOE} and T_{DOD} are approximately expressed as follows:

$$T_{DOE}=C_E V_D/I_0 \qquad \dots (3)$$

$$T_{DOD}=(C_D+C_i)(\Delta V)/(\eta_E \eta_D I_0) \qquad \dots (4)$$

Here, C_E and V_D denote a terminal capacitance and a terminal voltage, respectively, C_D denotes a terminal capacitance of a light receiving element, Ci denotes an input capacitance of an element connected to the terminal of the light receiving element in order to detect an electric signal, and η_E and η_D denote a light emitting efficiency and a light receiving efficiency, respectively.

As clearly seen from the above equation, time delay of signal transmission due to use of the conventional electric

signals as such is dependent on the length L of the wiring, and on the other hand because time delay in case of being converted into optical signals is not dependent on the length of the wiring. Therefore when assuming fabrication technique to be same, comparison can be made as to up to which length of wiring the conventional system is higher in speed; and as to whether or not the optical conversion system is superior in case where the length of the wiring is higher than the minimum wiring length L_{min}. Its answer is as follows. L_{min} is about 1mm in the present fabricating technique of 3 to 4μm rule, while the actual length of wirings is longer than L_{min}, and when considering that wiring length L will be much longer and L_{min} will become lower according to improvement in integration density as expected in the future, it is considered that $T_{DO} \leqq T_{DE}$ in spite of requiring photo-electric conversion time. In addition, when the line width of integrated circuit becomes lower than 1μm, it cannot be expected that the floating capacitance C_W of the wiring become lower proportional to miniaturization of line width, and delay in unit length of wiring has a low improvement degree in miniaturization of 1μm or less. On the other hand, delay time in the optical conversion transmission system is shortened proportional to about a square of miniaturization, and it can be finally judged that the optical conversion system is advantageous with respect to the most part of wiring lengths.

In this way, it is included that the optical conversion system herein suggested by the present inventor is superior to the conventional wiring system.

Fig. 1 shows one example of the present invention based on this knowledge or principle.

Like the conventional integrated circuit structure, a

substrate 1 is formed by stacking a semiconductor layer on a semiconductor crystal or an insulating material base layer, and a plurality of unit semiconductor integrated circuits are formed thereon. By the way, since the present invention is not directly defined by each of unit circuits themselves, their illustration and explanation are omitted.

An insulating film 2 is generally provided on the surface of the substrate 1 for separation between electric wiring regions of integrated circuit and between elements, but in the present example 1, the insulating film 2 is utilized as a kind of a clad layer for an optical waveguide path 3 formed thereon. Thus, in case that the insulating film 2 is not formed in a region where the optical waveguide path 3 is formed, additional insulating film, clad film, or reflecting film may be intentionally formed, and the optical waveguide path 3 may be also formed directly on the substrate 1 if the refractive index of the substrate 1 is lower than that of the optical waveguide path 3 to be formed.

Transmission sections Ei, i= 1,2,3,... of one unit circuit are disposed on one end of the optical waveguide path 3, and reception sections Di, i=1,2,3,... of another unit circuit which receives signals from the former unit circuit are disposed on the other end of the optical waveguide path 3. Each unit circuit may have a plurality of transmission and a plurality of reception sections if necessary.

Specific examples of constitution of each transmission and reception section are shown in the drawings. As the transmission section Ei, an electro-photo-converting light-emitting element 4 such as a light-emitting diode, or a semiconductor laser are preferable to be disposed on the substrate 1, and it is disposed such that light from its active region or light emitting section 6 is projected into the optical waveguide path 3. The electrode portion 5 for

driving this light emitting element 4 may be formed in the surface of the substrate as shown in the drawings.

On the other hand, a light receiving element 10 as the reception section Di may be constituted to form pn junction, for example, between the first region 7 provided in a part of the substrate surface and the second region 1a as the peripheral part of the first region of the substrate 1, and when the first region 7 is brought into contact with a predetermined electric signal input terminal of the unit circuit having the reception section of the first region, voltage variation generated in the region 7 can be detected as information signal. In addition, the optical waveguide 3 is formed in a downwardly curved shape toward the substrate in order to guide light into this reception section. In order to prevent light leakage especially in the downwardly curved end portion and the end portion in transmission section side, a reflecting film 8 is attached on the peripheral surface of the end portions. However, since total reflection is occurred when the angle of the end portion of the optical waveguide path with respect to a light traveling direction is not less than a critical angle, there is also a case of not requiring the reflecting film 8 especially. The same may be said in case where a lattice with an interval matching with a wavelength of light to be used is disposed on the end portion of the optical waveguide path.

Furthermore, in case that a sectional size of the optical waveguide path 3 is enough larger than the wavelength of light to be used, the propagation state of light wave in the optical waveguide path is represented by geometrical optics, and therefore there is no need for the optical waveguide path to be linear. For example, the optical waveguide path may be disposed with a few curved lines being connected. In this case, highly efficient transmission

property can be achieved, if necessary, by providing a light reflecting film on the outside of the optical waveguide path so as to prevent light leakage from the optical waveguide path.

The first example has been described hereto, but it is also considered that when the sectional size of the optical waveguide path is miniaturized to the extent of being equal to the wavelength of light in the optical waveguide path, the light propagating state in the optical waveguide path cannot be expressed by geometrical optics with a result of not permitting easy curving of the optical waveguide path. To cope with this, much higher accuracy of processing technique and much higher quality of optical waveguide materials are required, thereby falling into a state where a yield of the whole system is lowered and then cost reduction is difficult to be achieved.

Fig. 2 shows the second example which overcomes this problem. Elements in Fig. 2 corresponding to those in the first example are represented with the corresponding reference numbers, while, as shown in Fig. 2(a) which is a plan view of the optical waveguide path 3 taken alone, the second example does not employ each of the optical waveguide paths in a stripe shape which is used for only one pair of transmission and reception sections, but employs a plane-shaped optical waveguide path 3 as a common optical waveguide path structure, and, also in the second example, transmission sections Ei and reception sections Di of each unit circuit to be interconnected with the plane-shaped optical waveguide path 3 are arranged at a plurality of positions on the side walls of the optical waveguide path 3.

Fig. 2 briefly shows three transmission sections E_1 to E_3 and reception sections D_1 to D_3, each being paired one by one, wherein each pair is disposed on each apex of the plane-

shaped optical waveguide path 3 having a substantially triangular shape. Each apex is planed off so that one pair of the transmission and reception sections is easily positioned, and therefore it can be said that the plane-shaped optical waveguide path 3 appears to be a hexagonal shape formed by alternately using short sides and long sides, and each pair of the transmission and reception sections is positioned at each short side.

Of course, the shape of the plane-shaped optical waveguide path is not limited to the above-mentioned shape, but is arbitrary, and also the number of unit circuits or the number of the transmission and reception sections may be arbitrary as needed.

As shown in the sectional view of Fig. 2(b), light emitting elements 4 and light receiving elements 10 constituting each transmission section and reception section may be suitably composed of the same constitution as shown in Fig. 1. In addition, in such a constitution of the optical waveguide path, the light emitting section 4 may be, for example, endowed with a directivity so as to send light only to a specific light receiving element, and as shown with arrow I in Fig. 2(a), a non-directive light-emitting diode may also be utilized to transmit light to all light receiving elements 10 ···. Whether or not the received light signal is utilized as an information may be leaved to the option of each unit circuit.

When the optical waveguide path is formed in a plane shape as this example, its sectional size may be given sufficiently larger than the wavelength of light wave therein, consequently avoiding the above noted restriction.

Further, Fig. 2(b) schematically shows a semiconductor integrated circuit 11 which is formed by the conventional technology and performs a desired function by processing

electric signals.

Regardless of the first and second examples, it is preferable that the material of the optical waveguide path has no absorptiveness of light wave therein, or if it has, a extremely lower absorptiveness. For example, it is preferable that the material has band gap sufficiently larger than the energy of light wave therein.

Next, preferable examples are described in detail as follows regarding materials and fabrication method.

In case that the substrate 1 is made of silicon, the light emitting element 4 may be a red light emitting diode formed by introducing Zn atoms and O atoms, or a green light emitting diode formed by introducing N atoms into GaP as a light emitting center which can epitaxially grow on the silicon substrate by way of liquid or gas phase epitaxial method, MBE or the like, where GaP not doped with impurities may be used for the optical waveguide path 3 as suitable in this case. Since the energy of light passing through the optical waveguide path of GaP is lower than a band gap of the corresponding GaP, undesirable light absorption can be avoided.

In addition, when an opening is formed in the insulating film 2 on the substrate 1 and then an epitaxial growth of GaP is performed, single crystal of GaP can be grown in the opening, and polycrystal or amorphous GaP is grown on the insulating film. And, when N atoms, Zn atoms and O atoms are selectively introduced into GaP single crystal formed on the opening, the light emitting element, the light receiving element and the optical waveguide path can be formed as one body, thereby permitting omitting of a position matching step for each of the light emitting and receiving elements and the optical waveguide path, which is required in case of forming them separately. Light emitting

mechanism includes a mechanism of forming pn junction in GaP, or a mechanism by hetero structure to inject carriers from a junction face between the region 5 and GaP.

When growth of $Ga_xIn_{1-x}P$ is performed on GaP in the portion of the light emitting element, a light emitting wavelength becomes smaller than band gap energy of GaP used in the waveguide path, thereby not causing the light absorption like the above case. Further, a laser diode may be formed in case where the amount of In is increased. Laser emitting is allowed by employing the hetero structure of (p-type GaP)/(p- or n-type $Ga_xIn_{1-x}P$)/(n-type GaP).

As explained above in detail, the present invention can decrease signal transmission delay due to the wiring of semiconductor integrated circuit formed on the same substrate or chip, and can achieve improvement of performance corresponding to miniaturization, and can achieve a high-speed signal transmission among the unit circuits and a high-functionality of the whole system.

Furthermore, in case of the plane-shaped structure of the optical waveguide path as shown in Fig. 2, integrated optical pass function can be achieved by utilizing LED with low directivity as a light emitting element. That is, when light emitting elements as signal transmitting terminals and light receiving elements as signal receiving terminals are coupled in required number at the end portion of the plane-shaped waveguide path, signals can be transmitted from one transmitting terminal to one receiving terminal with signal delay much lower than that in case of using the conventional electric signal pass line.

4. BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1(a) is a schematically constitutional plan view showing the first example of the present invention;

FIG. 1(b) is a sectional end view taken along the line

X-X of FIG. 1(a);

FIG. 2(a) is a schematically constitutional plan view showing the main portion of the second example; and

FIG. 2(b) is a sectional end view taken along the line X-X of FIG. 2(a).

1: substrate, 3: optical waveguide path, 4: light emitting element, 10: light receiving element, Ei: transmission section, Pi: reception section.

なわち、この面状導波路の端部に信号送端としての発光素子、信号受端としての受光素子を必要個数結合しておけば任意の送端から任意の受端へ、従来の電気信号バスラインを用いたときの信号遅れよりはるかに小さい遅れで、信号の送信が可能となる。

4.図面の簡単な説明

第1図(a)は本発明第一の実施例の平面図的な概略構成図、第1図(b)は第1図(a)中のX－X線に沿う断面端面図、第2図(a)は第二実施例の平面図的な要部概略構成図、第2図(b)は第2図(a)中のX－X線に沿う断面端面図、である。

図中、1は基板、3は光導波路、4は発光素子、10は受光素子、Eiは送信部、Piは受信部、である。

FIG. 1(a)
第1図 (a)

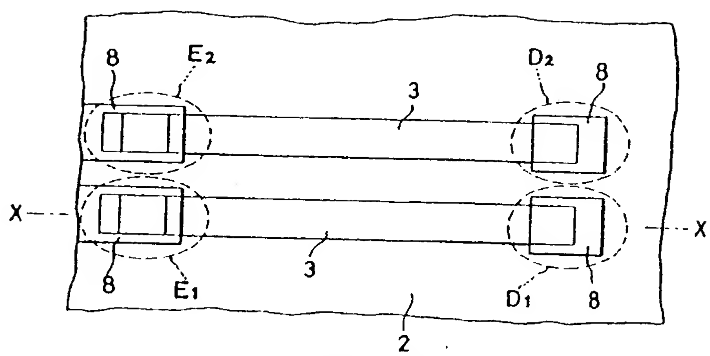
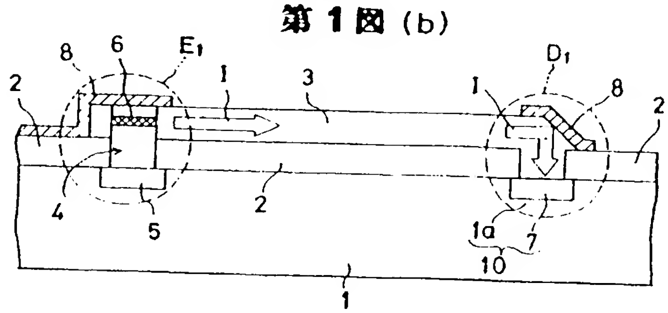


FIG. 1(b)
第1図 (b)



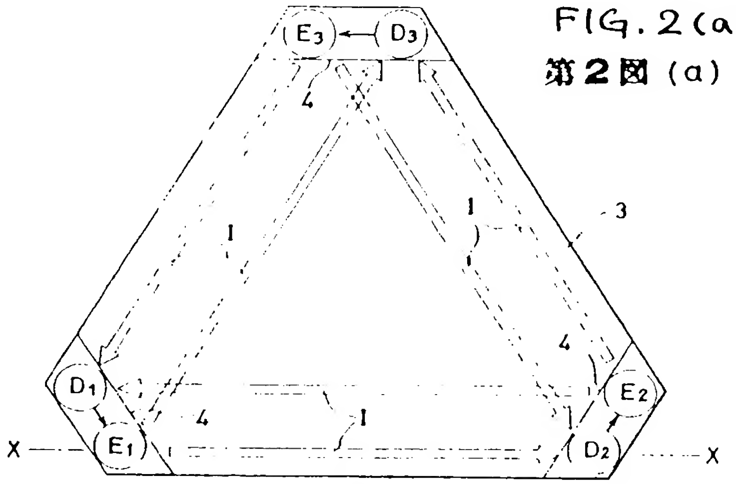


FIG. 2 (a)
第2図 (a)

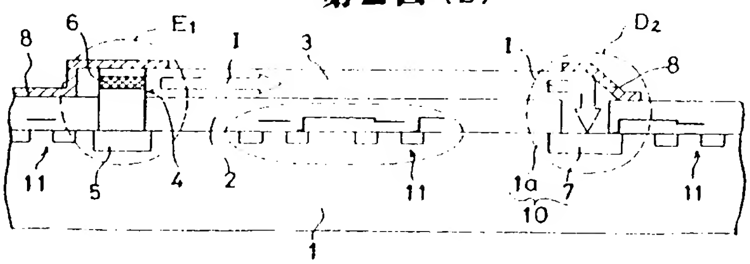


FIG. 2 (b)
第2図 (b)